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Predicting the potential susceptibility of surface waters to changes in the boreal forest: towards adaptive forest management strategies

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Predicting the susceptibility of surface waters to changes in the boreal forest: towards an adaptive forest management tool

A NETWORK OF CENTRES OF EXCELLENCE
UN RÉSEAU DE CENTRES D'EXCELLENCE

PREDICTING THE POTENTIAL SUSCEPTIBILITY OF SURFACE WATERS TO CHANGES IN THE BOREAL FOREST: TOWARDS ADAPTIVE FOREST MANAGEMENT STRATEGIES

FINAL REPORT FOR THE NCE-SFM FUNDED PROJECT

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RESEARCH PROBLEM

The Canadian Boreal Forest is one of the world's major repositories of northern forests. Increasing demands for natural resources have resulted in about 50% of the Canadian Boreal Forest being allocated for timber harvesting and for oil and gas exploration *Global Forest Watch Canada*, 2002]. Such activities may have direct impacts on aquatic systems [e.g., blockage of amphibian and/or fish migration corridors] or indirect impacts on aquatic systems [e.g., increases in water, sediment, and nutrient transport from cut blocks to surface waters]. While recent research activities have focused on assessing the effects of these disturbances on aquatic systems, the research needs to be conducted on the hydrological processes that control water, sediment, and/or nutrient transport from forested areas and the implications of disturbances on these processes *Buttle et al.*, 2000; *Buttle et al.*, Submitted]. This research project address this research need by using a combination of ground- and satellite-based methods to: [1] Characterize hydrologic linkages between land and lakes; and [2] Establish the relation between hydrologic linkages and the nutrient status of a lake. A third objective, that focused on exploring the relation between potential of hydrologic linkages between land and lakes, the nutrient status of a lake defined by "bottom up" controls and the nutrient status of a lake defined by "top down" controls as defined by the fish community in the lake was not funded and is not presented.

CONCEPTUAL MODEL

In a previous research project, I.F. Creed and K.J. Devito developed a conceptual model of the potential susceptibility of surface water to disturbances in the landscape Figure 1, *Devito et al.*, 2000]. We proposed that the position of a lake within the landscape explains a significant portion of the natural variability in hydrologic dynamics and, because of the hydrologic link between land and surface waters, it is a likely correlate of the potential susceptibility of surface waters to disturbances in the landscape.

Landscape Factor	Potential Susceptibility of Surface Waters to Disturbances in the Landscape	
	← Higher susceptibility	Lower susceptibility →
Lake Order	First or lower order lake	Higher order lake
Lake Elevation	High elevation lake relative to the regional drainage basin	Low elevation lake relative to the regional drainage basin
Lake Position	Lake within local hydrologic or recharging flow system	Lake within regional hydrologic or discharging flow system
Mechanism of runoff generation	Saturation overland flow dominates	Subsurface flow dominates
Size of runoff generating areas	Larger surface saturated areas	Smaller surface saturated areas
Organization of runoff generating areas	Higher connectivity of surface saturated areas to lakes	Lower connectivity of surface saturated areas to lakes
Filtering capacity of land-lake interface [i.e., riparian areas]	Concave topographic profiles from land to lake reflect higher water tables, greater chance of overland flow paths, and lesser interaction with roots and sediments in vegetated buffers	Convex topographic profiles from land to lake reflect lower water tables, lesser chance of overland flow, and if the confining layer is shallow then greater interaction with roots and sediments in vegetated buffers

FIGURE 1 A conceptual model of the hierarchy of landscape factors that influence e the potential susceptibility of surface waters to human activities.

For the Boreal Plain, important factors for characterizing landscape position include the size and organization of runoff generating areas within the drainage basin of a lake. We defined runoff-generating areas as **surface saturated areas** [**SSAs**] that provide effective surface pathways of water directly to lakes and, thus, influence the potential of exporting dissolved and particulate nutrients. We anticipated that the relatively organized hydrologic portals that occur on the Boreal Shield [where SSAs connect directly to the lake or indirectly via streams to the lake] would contrast with the relatively disorganized hydrologic portals that occur on the Boreal Plain [where SSAs shift from a state of being disconnected during dry periods to connected during wet periods].

For this "pilot" research project, we focused on the aspen dominated Moose Lake drainage basin [55˚07'58"N, 111˚46'17"W] in the mixed-wood Boreal Forest Ecoregion of the Boreal Plain Ecozone in northern Alberta, Canada Figure 2]. Moose Lake is characterized by a gentle topography and a stratigraphy of glacial drift that ranges from 20 to 200 m in thickness and contains complex inter-beds of clays, sands, and gravels *Devito et al.* 2000].

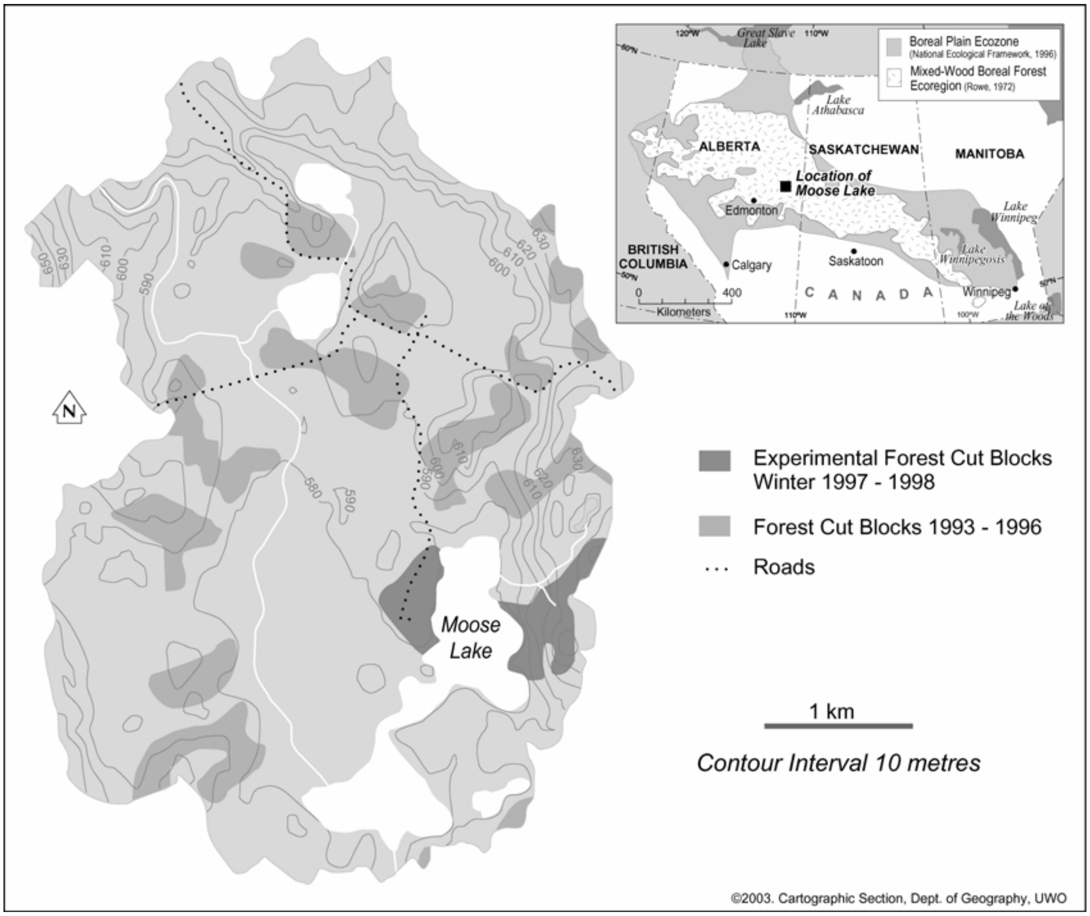

FIGURE 2 A map of Moose Lake drainage basin and the location of the drainage basin within the mixed-wood Boreal Forest on the Boreal Plain Ecozone

We made significant progress towards establishing the range of natural variability in SSAs within the Moose Lake drainage basin using ground- and satellite-based monitoring techniques *Devito et al.*, In Press; *Wolniewicz et al.*, Submitted]. Establishment of the relations between the range of natural variability in SSAs, the nutrient content in SSAs, and the nutrient status of the lake are ongoing *K.J. Devito and I.F. Creed*, Unpublished Data].

SCIENTIFIC FINDINGS

Hydrology

During our research project, significant variability in climatic conditions provided the opportunity to contrast water balances in relatively dry, average, and wet years. In all years, the water balance of the drainage basin was dominated by soil water storage. When significant runoff occurred, it originated in areas where soil water storage capacity is restricted by a shallow depth to the confining layer, including ephemeral draws and valley bottoms. An analysis of the regional water balance over the past 30-yrs indicated that the potential to exceed the soil water storage capacity and generate significant runoff occurs only once every 10-20+ years. With a shift in dominance from land-atmosphere to land-water hydrologic fluxes, these SSAs vary from small areas that concentrate along ephemeral draws and valley bottoms during dry conditions to large areas that expand from valley bottoms to contributing hillslopes during wet conditions. This dynamic of SSAs may, in turn, affect the potential for nutrient loading to lakes, raising a concern for surface water quality. Prediction of the potential impacts of resource management activities on surface water quality is complicated by challenges in monitoring the spatial heterogeneity of the water storage capacity of the soils and the temporal variability of the degree of water saturation of the soils within these drainage basins.

The remote sensing techniques used in this research project offer a realistic approach for monitoring hydrologic dynamics over large time and space scales, a significant challenge in hydrologic research particularly in remote regions *Buttle et al.*, Submitted]. Radar imagery showed substantial variation in SSAs both within a year and among years. Within a year, SSAs oscillated from small [prior to major hydrologic events in the summer] to large [during the major hydrologic events] and then small again. When at their minimum, SSAs were concentrated in topographic depressions and flats, with little hydrologic connections among different SSAs. During major hydrologic events, SSAs expanded beyond the topographic depressions and flats to include valleys and contributing hillslopes *Wolniewicz et al.*, Submitted]. While the radar-based estimates of SSAs corresponded to ground based estimates of SSA *Devito et al.*, In Press], radar imagery may not be effective in estimating all potentially important hydrologic features. For example, peatlands, dominating systems in much of the boreal landscape, may have a hydrologically active layer [i.e., acrotelm] where the water table can occur “near” the surface but below the depth detected by the radar remote sensing techniques.

Research needs to be conducted on the role of peatland storage and runoff on the hydrologic portals and the potential of radar remote sensing techniques in mapping hydrologic dynamics in peatlands.

Soil and Ground Water Nutrient Concentrations

Soil moisture, phosphorus, and nitrogen measured across a toposequence from upland to wetland in both harvested [cutblocks] and forested sections of a catchment draining into Moose lake [Figure 2] were related to surface and ground water phosphorus Redding *et al.* 2003; Macrae *et al.* Submitted; Macrae *et al.* In Prep.] Topographic position explained most of the variance in soil moisture, phosphorus, and nitrogen contents of surface soils [0-20 cm] and there was little difference between harvested and forested areas. Soil phosphorus was inversely related to soil moisture throughout the catchment. Following drought elevated soil nitrogen levels were observed in wetland soils Kalef 2002; Redding et al. 2003].

Surface organic soils [0 -10 cm] were higher in extractable and total phosphorus and nitrogen compared to mineral soils *Redding et al.* 2003]. Phosphorus buffering capacity was low in organic surface soils [EPC > 5000 μg l^{-1}] and high in subsoils [EPC =100-400 μg l^{-1} in A horizon; EPC < 100 μg l^{-1} in B horizon] Macrae *et al.*, Submitted]. This is reflected in higher dissolved phosphorus and nitrogen concentrations in surface water relative to ground water throughout the catchment. Changes in ground water phosphorus following a harvest are unlikely in this catchment due to the high adsorption affinity of mineral subsoils. Phosphorus and nitrogen-rich surface soils have a high potential for release to surface water but this does not differ between forested and harvested sections of the catchment. Natural climatic variability in this sub-humid area often prevents surface runoff and discharge from occurring. The effects of harvesting may be dampened in sub-humid areas such as the Boreal Plain due to the moisture deficit. However, our ability to evaluate the effects of harvesting on phosphorus dynamics in this region is confounded by natural climatic variability and spatial variability within catchments.

MANAGEMENT IMPLICATIONS

The natural variation in SSAs revealed by radar imagery may be important for several forest management issues. For example, this study and previous studies have shown ephemeral draws and wetland areas may be source areas for nutrients, such as nitrogen and phosphorous *Kalef,* 2002; *Macrae et al.,* Submitted; *Macrae et al.,* In Prep.]. These areas of high nutrient concentrations in near surface saturated areas are often associated with SSAs, and as such may function as corridors of nutrient loading from land to waters. The connectivity of the SSAs, therefore, may affect the nutrient status of surface waters e.g., *Devito et al.*, 2000]. SSAs may also function as biodiversity hotspots providing habitat for a wide range of species and/or corridors for dispersal of pollen and seed and movement of organisms [e.g., fish, amphibians] within the landscape. Although variable in nature in both space and time, SSAs provide unique physical, chemical, and biotic properties and; thus, should be maintained to protect the function of boreal ecosystems.

A common practice in forest management is to leave buffer strips of riparian forest between harvested areas and adjacent surface waters to trap dissolved and particulate nutrients in hydrologic flows, and thereby, reduce nutrient loading from harvested areas to surface waters *Castelle et al.*, 1994]. Current guidelines on the Boreal Plain [Alberta] require that a standardized width of buffer strip be left around wetlands [20 m], streams [30 m], rivers [60 m] and lakes [100 m] *AEP*, 1994]. These guidelines fail to consider the hydrologic characteristics of the landscape *Buttle*, 2002], with the standardized widths of buffer strips offering too much or too little protection for surface water quality *Belt and O'Laughlin*, 1994]. The lack of a hydrologic basis in the design of buffer strips may explain conflicting results among studies that evaluated the effectiveness of standard widths of buffer strips on surface water quality in the boreal forest. For example, the Terrestrial, Riparian, Organisms, Lakes and Streams [TROLS] research project assessed the effectiveness of standardized widths of buffer strips in conserving the nutrient status of lakes following harvesting *Prepas et al.*, 2001]. While post-harvest increases in the concentration of phosphorus [a limiting factor for primary production in boreal lakes] were observed, these increases were not related to the width of the buffer strips. Buffer strips of 20 m, 100 m [the current guideline], 200 m, and 800 m in width had no effect on the phosphorus loading to lakes following harvest activities *Prepas et al.*, 2001]. Rather, lake position in the groundwater flow system and connectivity of SSAs were implicated as important in identifying the susceptibility of receiving aquatic systems to disturbances and in determining the effectiveness of buffer strips in mitigating the impacts of disturbances *Devito et al.*, 2000].

An alternative to the standard width design of buffer strips that incorporates the range in natural variation of SSAs within the watershed is demonstrated in Figure 3. Current forest management guideline requires a standard width of buffer strip of 20 m around wetlands, 30 m around streams, 60 m around rivers, and 100 m around lakes *AEP*, 1994] [Figure 3a]. For a return period of 1.1 yr [i.e., the summer maximum that occurs on average once each year], the SSAs are larger than required for streams, but are smaller than required for wetlands, or lakes [Figure 3b]. In contrast, based on a return period of 5 yr [i.e., the summer maximum that occurs on average once every five years], the SSAs are larger than required for streams and wetlands, but still do not extend around the entire lake [Figure 3c]. Selection of a specific return period to form a basis of a hydrologically-based design for buffer strips should consider a number of factors including the intensity of harvesting activities within the watershed and the sensitivity of the lake to changes in nutrient loading. To mitigate the potential impacts of timber harvests on nutrient loading to lakes, timber harvesting should not occur within SSAs [to maintain the range of natural variation] and buffer strips should be placed at the boundary of the SSAs where surface waters from cutblocks flow into the SSAs [to minimize enhanced nutrient loading to the SSAs].

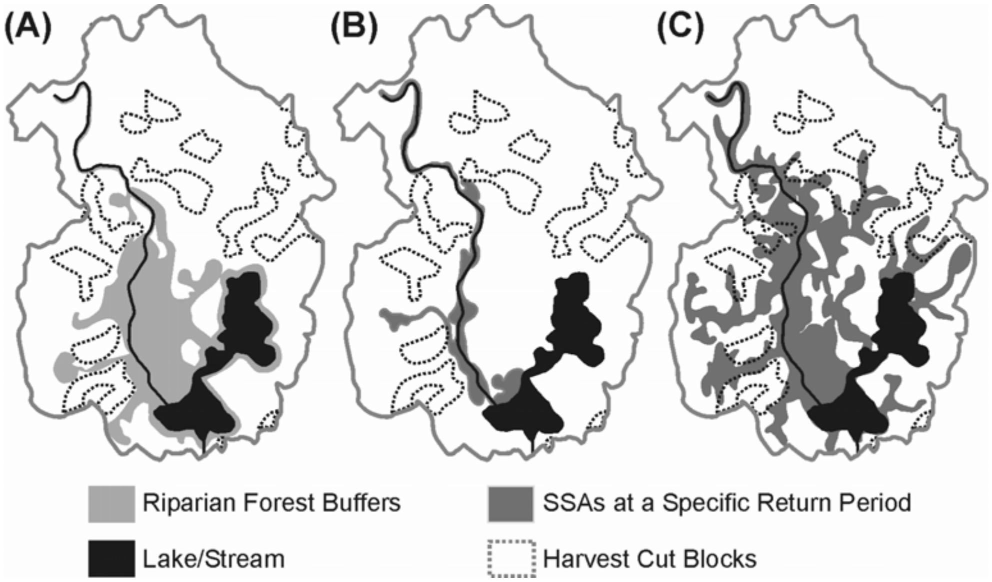

FIGURE 3 A map of [A] the current buffer strip management policy [100 m buffer strip surrounding lake, 30 m buffer strip surrounding streams, and a 20 m buffer strip surrounding wetlands]; [B] the extent of the SSAs for a return period of 1.1 yrs; and [C] the extent of SSAs for a return period of 5 yrs. Each map is superimposed with cut blocks that occurred in the past decade.

Based on our research findings, we propose an adaptive guideline for buffer strips that reflects the hydrologic characteristics of the landscape and location of nutrients available for hydrologic transport. We offer an approach that can be used to implement the adaptive guideline based on monitoring and modeling [the latter being developed in an ongoing research project] techniques.

FUTURE RESEARCH

The focus of this report is on characterization of hydrological linkages between land and lakes, the first objective of the original proposal and the foundation of two M.Sc. theses *Wolniewicz,* 2002; *Kalef* 2002] and two manuscripts submitted to internationally recognized hydrologic journals *Devito et al.,* In Press; *Wolniewicz et al.,* Submitted]. Ongoing research activities focus on the stocks and transformations of nutrients along these hydrological linkages *Macrae et al.,* Submitted; *Macrae et al.,* In Prep.] and on the nutrient status within the lake *I.F. Creed,* Unpublished Data], the second objective of the original proposal.

This research project enabled us to develop our technical capabilities for monitoring and modeling hydrological processes on boreal landscapes. This research project served as a catalyst for the ongoing NSERC-CRD, Alberta Pacific Forest Industries Ltd., Weyerhaeuser Ltd., and Ducks Unlimited Canada funded project referred to as the **Hydrology, Ecology, And Disturbance** of wetland ponds of the Western Boreal Forest [**HEAD**] project. The HEAD project, which includes 100+ synoptically monitored ponds and 24 continuously monitored ponds, will lead to further development of our conceptual understanding of hydrological processes in this complex landscape.

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REFERENCES

Alberta Environmental Protection, Alberta timber harvest planning and operating ground rules, Natural Resources Service, Recreate and Protected Areas Division. Edmonton, Alberta, 1994.

Belt, G.H., and J. O'Laughlin, Buffer strip design for protecting water quality and fish habitat, *West. J. Appl. For.*, *9*, 41-45, 1994.

Buttle, J.M., Rethinking the donut: the case for hydrologically relevant buffer zones, *Hydrol. Process.*, *18*, 3093-3096, 2002

Buttle, J.M., I.F. Creed, and J.W. Pomeroy, Advances in Canadian forest hydrology, 1995-1998. *Hydrol. Process.*, *14*, 1551-1578, 2000.

Buttle, J.M., I.F. Creed, and R.D. Moore, Advances in Canadian Forest Hydrology, 1999-2003. *Hydrol. Process.*, Submitted.

Castelle, A.J., A.W. Johnson, and C. Connolly, Wetland and stream buffer size requirements: A review, *J. Environ. Qual.*, *23*, 878-882, 1994.

Devito, K.J., I.F. Creed, R.L. Rothwell, and E.E. Prepas, Landscape controls on phosphorous loading to boreal lakes: implications for the potential impacts of forest harvesting, *Can. J. Fish. Aquat. Sci.*, *57*, 1977-1984, 2000.

Devito, K.J., I.F. Creed, and C.J.D. Fraser, Controls on runoff from aspen dominated headwater catchments on the Boreal Plain: Implications for forest management, *Hydrol. Process.*, In Press.

Global Forest Watch Canada, Canada's Forests at a Crossroads: An assessment in the Year 2000, 107 pp., Edmonton, Alberta, 2002.

Kalef, N., Interlinking hydrological behaviour and inorganic nitrogen cycling in a forested boreal wetland, M.Sc. Thesis, University of Alberta, Edmonton, Alberta, 83 pp, 2002.

Macrae M.L., K.J. Devito, T. Redding, I.F. Creed, and W. Bell, Soil phosphorus in relation to surface and ground water phosphorus in harvested and forested portions of a sub-humid boreal aspen upland, *Hydrol. Process.*, Submitted.

Macrae M.L., K.J. Devito, T. Redding, I.F. Creed, and E. Macdonald, Surface and ground water and soil nitrogen in harvested and forested portions of a sub-humid boreal aspen upland, *Can. J. For. Res.*: In Prep.

Prepas, E.E., B. Pinel-Alloul, D. Planas, G. Methot, S. Paquet, and S. Reedyk, Forest harvest impacts on water quality and aquatic biota on the Boreal Plain: Introduction to the TROLS lake program, *Can. J. Fish. Aquat. Sci.*, *58*, 421-436, 2001.

Redding T.E., K.J. Devito, N. Carmosini, and I.F. Creed. Influences of topography and harvesting on the spatial distribution of soil moisture, nitrogen and phosphorous across a western boreal forest watershed, Proceedings of Alberta Soil Science Workshop, Edmonton, Alberta, February 18-20, pp. 265-269, 2003.

Wolniewicz, M.B, Hydrologic portals: Surface pathways for nutrient loading to Boreal lakes. M.Sc. Thesis, University of Western Ontario, 114 pp., London, Ontario, 2002.

Wolniewicz, M.B., I.F. Creed, and K.J. Devito, Hydrologic portals: A physically based method for designing buffer strips, *Water Resour. Res.*, Submitted.